

AN APPROACH OF DIFFERENTIAL CAPACITOR SENSOR FOR LANDSLIDE MONITORING

S. M. A. Motakabber and M. I. Ibrahimy

Faculty of Engineering, International Islamic University Malaysia, 53100 KL, Malaysia

ABSTRACT: A lot of lives and properties are lost in every year all over the world, due to various geological catastrophes, landslide or land-slip is among one of them. Nowadays, both manual and electronic monitoring systems are used to predict the landslide. The manual monitoring system is laborious, has many limitations and most of the cases it is not practicable. Conversely, most of the electronic systems are complex and expensive. Most of the natural calamities occur without prior notice as a result, it damages the monitoring instrument as well. The monitoring sensor system should be planned as a spread network with a simple positional identification device such as RFID; hence the system can send the real time data without interrupt. In addition, the network should have a self-recovery, self-directed operation and actual data transmission facility in a critical situation. A distributed node network needs a lot of sensors with complex structure and it is expensive too. This paper describes a simple and low cost system which comprises an underground pretension cable with a capacitor gauge sensor attached at one end. A wireless sensor network has been proposed for a simple landslide monitoring system using RFID. The sensing node network can operate by initializing mode, measuring mode and urgent mode. The system is able to select automatically any one of the operating mode depending on the situation, which makes it a robust and dynamic control of real time data transmission system. A mathematical model has been developed for the system and verified by simulation. The result shows that an early prediction of the landslide is possible by using the proposed system.

Keywords: *Landslide, Capacitor Sensor, RFID, Wireless Sensor Network, Geological Catastrophe*

INTRODUCTION

It is very hard to forecast an exact time, date and place of incidence of many natural disasters like a landslide. Worldwide, landslide cause about 1,000 deaths per year and property damage of approximately US\$ 4 billion [1]. Therefore, a regular inspection and record is maintained around the hazardous area essential. If somehow we can catch some symptoms before the worst incidence, the information can help us to report to the residents and it can be useful to predict to operate the monitoring system efficiently. Existing manual solutions are insufficient and sometimes costly to landslide monitoring and prediction. Installing a single sensor for monitoring a wide hilly target area is not sufficient, since most of the cases the property on the hill is changed in about every 10-15 meters distance. Wiring with multiple sensors to a central data logger is also not practicable due to reliability and it requires frequent maintenance. Therefore, wireless sensor networks are used for real-time landslide monitoring system. A basic topology of a wireless sensor network is shown in Fig. 1. In this arrangement, all nodes addressed by RFID tag are wirelessly connected to each other and finally these are linked to the local base station (LBS1). Each node has at least one sensor to measure the

parameter of the land, such as temperature, land movement, velocity and acceleration of the landslide of the target area. Practically a large number of nodes are used for the landslide monitoring system.

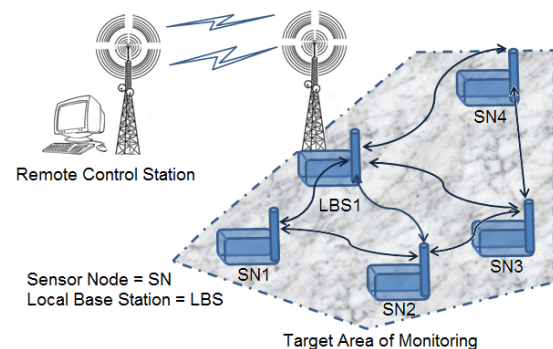


Fig. 1 Basic wireless sensor network for landslide monitoring

For simplicity of the structure, each node addressed by RFID tag, has a short distance communication facility (about 100m). It is sufficient to make a network for a large area. However, it is not enough to communicate with a secure distance during disaster time. Different algorithm and wireless protocol can be used between the nodes and LBS1 for communicating with each other. The LBS1 has a

long distance communication facility with the remote control station, which is connected with the server. Therefore, the server can always receive real-time data of the sensor through LBS1.

A capacitor type sensor can be used for monitoring the land movement. A thin film strain gage pressure sensor with high accuracy pressure measurement is claimed [2]. A simple pretension underground cable attached with a strain gage at one end can be used to measure the pressure of the soil for the landslide monitoring system [3]. But it introduces noise and needs a complex thermal adjustment. A differential capacitor sensor of wireless sensor network for landslide monitoring has been proposed as shown in Fig. 2 which introduce less noise and low thermal adjustment. The differential capacitor sensor is simple, robust,

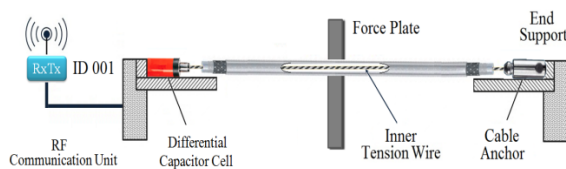


Fig. 2 Basic arrangement of a single sensor node for the proposed landslide monitoring system

reliable and chipper compares to other types of sensors. A slight movement of the soil produces a force on force plate as well as the pretension wire. A variable differential capacitor is connected to one end of this wire. Therefore, due to the movement of the land there is a change of the capacitance in the differential capacitor cell. This capacitance change can be used to calculate the landslide prediction and detection. An electronic circuit (used to measure the capacitance change) and a small distance (about 100m) wireless communication system are used to make a sensor node. A number of the same kind of sensors setup or node can be used for monitoring a wide land area. Thus, it is important to define each node carefully by a unique number by RFID tag within a wireless network to identify the exact location of the incident. This ID number can be easily used to locate the land-slip zone. A majority of the Wireless Sensor Network (WSN) arrangements are mainly data collection networks [4], [5]. The wireless sensor network will recurrently collect the respective data and collaboratively process measurements from the field under study before forwarding them to the central monitoring station. The central monitoring station will execute more computationally-intensive algorithms such as finite element modeling and parameter identification [6], [7] and will act as the expert interface to the system. A mobile communication system can be used to transmit the sensors sampled data and relevant information to a distant central database server computer for analysis purpose. The instant conveying of information will allow us to implement

instant disaster rescue measures and to notify the land user for protecting the people's lives and properties.

WIRELESS SENSOR NETWORK ALGORITHMS

Wireless sensor networks are one of the emerging electronic communication areas which have equipped scientists with the capability of developing real-time monitoring systems. The project has developed a new design methodology for wireless sensor network (WSN), where the high accuracy and reliability of the total sensor network is achieved through a proper interaction among nearby, proposed low cost differential capacitor sensors. This arrangement provides more accurate and robust distributed detection than that a single sensor system. Therefore, the WSN at the disposal site uses the same concept of a distributed detection, and estimation techniques to manage reliable decisions. The study mainly focuses on the detection of rainfall induced landslides, so the most relevant data has to be simulated based on the rainy season. Therefore, a threshold based algorithm is developed that influences the sampling rate of the physical sensors and the transmission of data to higher layers using rainfall and landslide pressure based alert levels. In this method, state level transitions have also been incorporated into the WSN node arrangement. As a result, it would reduce the energy consumption per node which will also contribute to reduce the energy consumption of the network. Now, wireless sensor network technology (WSNT) has created interest in scientists to learn and understand other domain areas which have helped them to develop a real-time control system. The environmental monitoring, detection and prediction is one of the major areas of application of the WSNT. The Drought Forecast and Alert System (DFAS) has been proposed in [8]; it uses a mobile communication system to alert the users. The real time data collection and transmission are carried out by using the wireless sensor nodes, WiFi, satellite network and also through the internet. The real streaming of data through broadband connectivity provides connectivity to a wide area of applications.

SENSOR MODELING

A simplified force diagram of the proposed landslide sensor that is, pretension cable with differential capacitor cell is shown in Fig. 3. Assume that a pretension steel cable of length L is attached with two end supports under the ground. If the cable linear expansion coefficient is α_L and the surrounding temperature of the cable is changed ΔT degree Kelvin then the change of cable length ΔL_T can be calculated as follows.

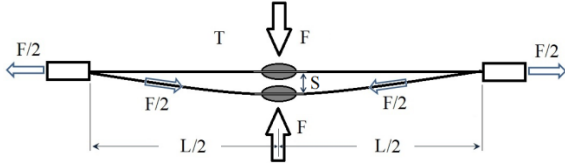


Fig. 3 Simplified force diagram of the proposed landslide pressure sensor

$$\alpha_L = \frac{1}{L} \frac{\Delta L_T}{\Delta T} \quad (1)$$

$$\text{Or, } \Delta L_T = \alpha_L L \Delta T \quad (2)$$

When the land is slightly moved to a distance S from its initial position then it will create a force F on force plate as well as on the cable. If the Yang's modulus of the cable is E then at force equilibrium condition be represented by Eq. (3).

$$E = \frac{F/A}{\Delta L/L} \quad (3)$$

Where, A is the cross sectional area of the cable and ΔL is the change in length of the cable due to force.

Considering the temperature effect,

$$\Delta L = \frac{F(L + \Delta L_T)}{EA} \quad (4)$$

The work U_E done by the movement of the soil can be calculated by Eq. (5).

$$U_E = FS \quad (5)$$

The potential energy U_W stored in the cable can be calculated as follows.

$$U_W = \int_0^{\Delta L} F d\Delta L \quad (6)$$

From Eq. (4) and Eq. (6), it can be written as follows.

$$U_W = \int_0^{\Delta L} \frac{EA\Delta L}{(L + \Delta L_T)} d\Delta L$$

$$\text{Or, } U_W = \frac{EA\Delta L^2}{2(L + \Delta L_T)} = \frac{\Delta LF}{2} \quad (7)$$

From Eq. (5) and (7), the potential energy U_C stored in the differential capacitor cell (supporting spring of the capacitor) can be calculated as follows.

$$U_C = U_E - U_W = FS - \frac{\Delta LF}{2}$$

$$\text{Or, } U_C = F \left(S - \frac{\Delta L}{2} \right) \quad (8)$$

Again, if the Yang's modulus of the spring of the differential capacitor cell is E_S then at force equilibrium condition can be calculated by Eq. (9).

$$F_S = \frac{E_S A_S \Delta L_S}{L_S} \quad (9)$$

Where, A_S and L_S are the cross section area and length of the supporting spring respectively, F_S is the force on the substrate and ΔL_S is the change in length of the substrate due to force. So the potential energy U_S storage in the spring can be calculated as follows.

$$U_S = \int_0^{\Delta L_S} F_S d\Delta L_S$$

$$\text{Or, } U_S = \frac{E_S A_S \Delta L_S^2}{2L_S} \quad (10)$$

Combining Eq. (8) and Eq. (10), it can be written as follows.

$$F \left(S - \frac{\Delta L}{2} \right) = \frac{E_S A_S \Delta L_S^2}{2L_S}$$

$$\text{Or, } \frac{\Delta L_S}{L_S} = \sqrt{\frac{2F}{L_{GS} E_{GS} A_{GS}} \left(S - \frac{\Delta L}{2} \right)} \quad (11)$$

A basic construction of a differential capacitor cell is shown in Fig. 4. If the cell factor and the temperature coefficient of the differential capacitor are k and α respectively, then the change of capacitance ΔC of the differential capacitor cell with respect to the total capacitance C can be calculated by Eq. (12).

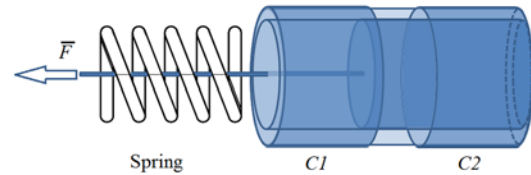


Fig. 4 Construction of a differential capacitor sensor cell

$$\frac{\Delta C}{C} = \left(\frac{k\Delta L_S}{L_S} + \alpha T \right) \quad (12)$$

Combining Eq. (11) and Eq. (12), the change of differential capacitance can be calculated by Eq. (13).

$$\Delta C = C \left(k \sqrt{\frac{2F}{L_S E_S A_S}} \left(S - \frac{\Delta L}{2} \right) + \alpha T \right) \quad (13)$$

From Eq. (4), if the Yang's modulus E of the cable is very large then $\Delta T \approx 0$ and Eq. (13) can be rewritten as Eq. (14).

$$\Delta C = C \left(k \sqrt{\frac{2FS}{L_s E_s A_s}} + \alpha T \right) \quad (14)$$

Equation (14) indicates that the change of capacitance of the differential capacitor cell is directly proportional to the square root of the force and displacement of the land.

RESULT AND DISCUSSION

A PSPICE simulation has been studied for the proposed landslide sensor for the monitoring system. The result is shown in Fig. 5. In this simulation, it is considered that the Yang's modulus E of the cable is infinity and the temperature coefficient of the capacitor cell is very low. From Fig. 5 it is found that from the beginning there is a very slow landslide effect and about four months later the effect is more visible. The sensor ID number 001 (RFID tag number) shows that its capacitance is changing exponentially; it means a massive landslide will be happened within a short time in the region under the sensor ID 001. The others sensor nodes also experienced some landslide effect.

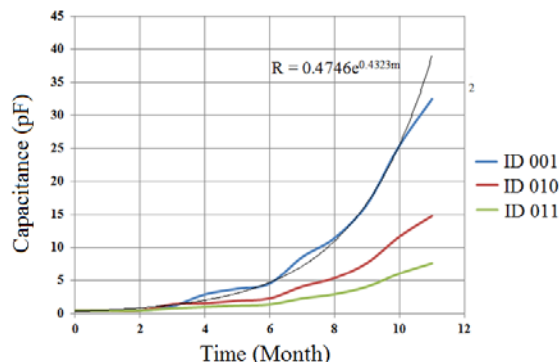


Fig. 5 Change of capacitance of the capacitor cell with time due to land movement

CONCLUSION

A pretension cable and a differential capacitor sensor with RFID tagged ID can be used for landslide prediction and detection purpose. The change of cell capacitance is a direct indication of the landslide effect. This principle can help to develop a simple and low cost real-time landslide or landslip monitoring system, where standard topology and algorithm are considered for wireless sensor network. According to the mathematical model Eq. (13) for an efficient system, the Yang's modulus of the cable must be very large. The steel and carbon fiber cable have a very large Yang's modulus and that can be appropriate to use in this development.

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Corresponding Author: M. I. Ibrahimy